SDU

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DM852

Heuristics & Approximations Algorithms

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Contents

1 Introduction

This project shows heuristics algorithms, which can resolve the Capacitated Vehicle Routing Problem (CVRP). If the heuristic can resolve the problem, we are going to apply Local Search algorithms to improve the results from the heuristics. The CVRP gives insight into how to deliver orders to customers using the shortest route for each vehicle, while preserving the capacity limit of each vehicle.
newline We have created two heuristic algorithms: one using a nearest-neighbour terminology and the other one taking inspiration of clustering close customers. We also show two self-implemented Local Search algorithms. Lastly, we are going to compare our own ideas against more common used algorithms, which are tested and proved to work.

> — Alexander & Narongrit

2 Custom Heuristics Algorithms

The first algorithm, which we have created, takes the approach of the Nearest Neighbour idea. Given an instance of CVRP, the starting point the depot where the vehicles are being loaded with customer requests is the point, where all calculations start. We start by checking the nearest point from the depot and add it to the first route. We then add the shortest path from the newly added point to the route and continue until we are out of capacity. Each point (customer) has a capacity, which adds up until the max is reached. We continue during the same from adding the first shortest route from the depot until we have reached our capacity limit. At one point, we have x amounts of routes, covering the problem instance.

Algorithm 1 Custom CVRP Heuristic - Nearest Neighbour Approach

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Require: $Point_1 \ldots Point_N$
Ensure: $Solution$ (solution to the CVRP instance)
 1: **function** ALGORITHM($Points[\,]$)
 2:     capacity $\leftarrow 0$
 3:     data $\leftarrow$ CVRP instance
 4:     visited $\leftarrow$ *empty array containing visited nodes*
 5:     shortestdistance $\leftarrow 0$
 6:     current $\leftarrow$ *keep track of next node to visit*
 7:     **for** i $\leftarrow 0$ to length of data-1 **do**
 8:         **for** j $\leftarrow 1$ to length of data **do**
 9:             $temp \leftarrow$ euclideandistance(current, j)
10:             **if** j not in $visited$ **then**
11:                 **if** $temp \leq shortestdistance$ **then**
12:                     $shortestdistance \leftarrow temp$
13:                     $current \leftarrow j$
14:                     $visited \leftarrow j$
     ▷ checking if capacity requirements are met
15:                     **if** current total capacity $\leq$ max capacity **then**
16:                         $capacity \leftarrow$ capacity of current node
17:                     **else**
18:                         Add starting point to end of route and
19:                         add capacity of current node to variable(capacity)
20:         $shortestdistance \leftarrow 0$ ▷ reset shortestdistance
21:     **return** $solution$

The first suggestion for an algorithm has a time complexity of $O(n^2)$. The algorithm has to iterate through the points of the instance twice. Given a point in the solution

space, we are trying to find the shortest distance to any point from the current point. When we have found it, we are marking the point, and making it the new current point. Then we continue to find the shortest distance to any non-visited point, while preserving the maximum capacity of the vehicle. If we find any shortest distance point from a current point, but it is going to break the maximum capacity limit, then we are returning to the depot, and start a new route.

Our next algorithm is inspired by Cluster Analysis [2], which is popular in machine learning and data mining. The idea is to group a set of points lying close to each other in an euclidean space. By choosing such approach to attack the Vehicle Routing Problem, we can ensure points are lying close to each other before we are deriving a route.

The heuristic algorithm has the following behaviour: (1) Pick a customer point furthest from away from the depot, which is not in the solution route; (2) Repeatly find nearest customer point from (1), which is not in any solution route and group such point together until the capacity is reached and save the points as a cluster; (3) Repeat (1) and (2) until we cover all customer points

The complexity of this algorithm is $O(n^2)$ since the main while loop terminates after we covered all customer points in given instance and for each iteration of while, we assume that we have auxiliary data structure stored distance between one point to another it can be perfrom in $O(n)$ time.

3   Custom Local Search Algorithms

While having created the heuristics, which provides us with solutions to the initial problem instances, we can still optimize. This is where the Local Search Optimization algorithms comes into play. Given a canonical solution, we want to optimize it to reduce the total cost of the solution. We have provided three custom Local Search (LS) algorithms, trying to optimize the canonical solution.

The first LS algorithm looks into the generated routes done by the heuristics. It takes two routes and compare them with each other, checking whether any swaps are possible in the two routes. A swap is possible if the distance is being reduced in at least one route, while still preserving the maximum capacity limit of both routes. The second LS algorithm looks like the first but with a minor change. It takes one route and compares it with every other route to find a better solution. It then continues doing this with every other route; take one route, compare it with every other route.

Algorithm 2 Custom CVRP Heuristic - Clustering Approach

Require: *customers*: List of customer Points
Require: *depot*: Depot Point
Require: *maxcap*: Maximum capacity for each route
Ensure: *routes*: Solution to the CVRP instance

 1: **function** ALGORITHM(*Points*, *depot*, *maxcap*)
 2:     excludelist ← *empty array containing visited nodes*
 3:     routes ← *empty array containing solution routes*
 4:     **while** $len(excludelist) < len(customers)$ **do**
 5:         capacity ← 0
 6:         route ← [depot]
 7:         startpoint ← $furthestpoint(depot, excludelist)$
 8:         excludelist ← *append the startpoint*
 9:         route ← *append the startpoint*
10:         capacity ← capacity + startpoint.capacity
11:         **while** $excludelist.length \leq customers.length$ **do**
12:             closest ← $closestpoint(startpoint, excludelist)$
13:             c ← $closest.capacity$
14:             **if** c + capacity > max capacity **then** break
15:             capacity ← capacity + c
16:             add closest to route
17:             add closest to excludelist
18:         add route to result set routes
19:     **return** *routes*

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4   Custom Local Search Algorithms

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5 Custom Local Search Algorithms 2

This localsearch algorithm for CVRP is inspired from the fact that if we wanted to find a customer point to move from one route to another, such point has to be the point that form convex hull of the route. We develop an algorithm from this fact to reduce number of comparison points of iteration each route by compute convex hull points of each route and only use those point as the candidate of interchanging points in routes. We also gain the addition benefit from haveing such list to estimate central of the route by computing average of convex hull point. We use the central point as the reference point of a route to find the closest point in others. These points are visulized in the figure, where lines are convex hull of a route. Point A and B are the closest points to central point from route i to route j (mid_j) and from route j to i (mid_i) respectively.

Figure 1: Convex hull points and central points of two routes
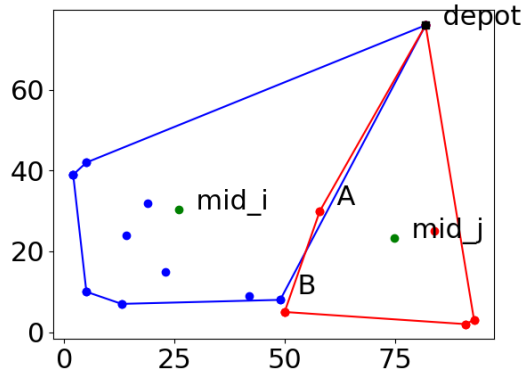
We implemented an algorithm according to [1] which has runtime complexity of $O(nlogn)$. The iteration of our localsearch is given by pair of routes namely i and j, we find the closest point from route i to j by comparing central point of convex i to central point of convex j and closest point from j to i respectively The possibilities of interchanging point from route i to j are following 3 cases

1. If the capacity constain from moving i to j is not exceeded. We compare if moving closest customer point of i to j produces better route, if so, we proceed moving point from i to j

2. If the capacity constain from moving j to i is not exceeded. We compare if moving closest customer point of j to i produces better route, if so, we proceed moving point from j to i

3. if the capacity constain from switching closest customer point of i to j is not exceeded. We compare if switching points of two routes produces better route, if so, we switch the candidate point from route i to route j and j to i respectively.

When we performing moving case (1 and 2) we should also take account of the tour order. As showing in figure 2a

(a) Move Case   (b) Swap Case
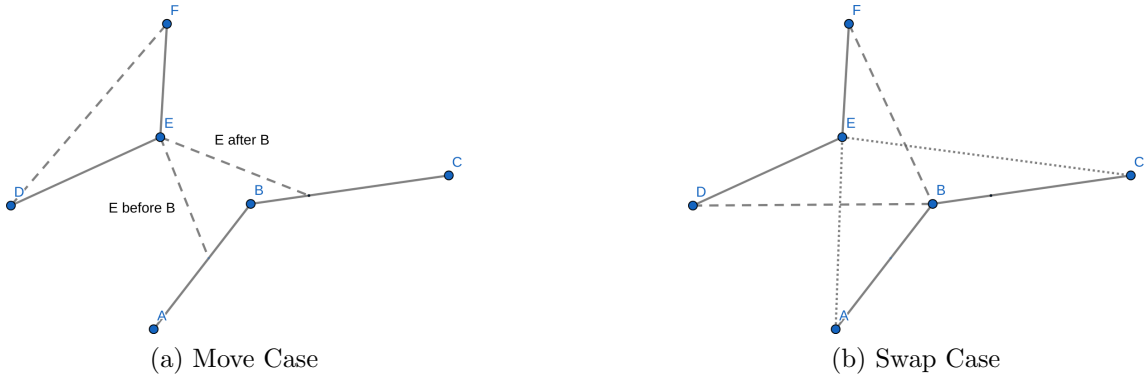
Moving point E which is the closest point in route j to i is resulted in different tour between visiting E before B or after. Thus, it is necessary to compare cost between these two sub cases before perform moving operation as showing in Line 9 of Algorithm 5. The complexity in main for all loop is $O(n^2)$ and all operation inside the loop has complexity at most $O(n)$ if we have the improvement of route, we recompute the convex_hull of 2 routes, thus, the complexity of each iteration of this localsearch is at most $O(n^3 log n)$

6   Performance Analysis & Boxplots

It has been a challenge to come up with our own custom solutions and the results we got from our algorithms and experiments were good. Our algorithms were built without being biased towards other existing algorithms. We tried to use our own imagination on how the problem could be solved. We have been inspired by concepts but not algorithms directly, and it has made us more aware on how to tackle problems and how not to.

We have tried to create boxplots for our custom algorithms to give an indication whether or not the algorithms performs somewhat similar on the same instance, but with a bigger dataset. Meaning: it is not completely random, even though the instance looks the same but has more data. If you look at the boxplot of our custom "close-index" local search algorithm 2a applied on the heuristic cluster

algorithm and compare it to the twoopt local search algorithm 2a applied on the same heuristic, then you are able to see the twoopt does better especially on the golden instances but on the other instances, we are getting there. All the boxplots can be found in the appendices.

7   Process Analysis

The group work went well. We were both enthusiastic about the work and wanted to try out as much as possible. The communication between us has been nice and we have been splitting out the work in somewhat equal pieces to adapt to the workload from other courses.

Alexander Lerche Falk

- Develop Nearest Neighbour Approach Heuristric

- Develop Custom Local Search Algorithms 1

- Performance analysis of Heuristics and Localsearchs

Narongrit Unwerawattana

- Develop Clustering Approach Heuristic

- Develop Custom Local Search Algorithms 2

both

- Writing report

References

[1] Mark de Berg, Otfried Cheong, Marc van Kreveld, and Mark Overmars. *Computational Geometry: Algorithms and Applications*. Springer, 1997.

[2] Wikipedia. Cluster analysis, March 2019.

Appendices

A

Custom Cluster Algorithm to solve CVRP

Algorithm 3 Cluster CVRP Localsearch

Require: $closest\_point(A, points)$: returns point in points which hase minimum distance from A

Require: $elim\_empty\_routes$: returns list of routes where the empty routes are removed

Ensure: $routes$: Better Solution to the CVRP instance

1: **function** ALGORITHM($routes$, $maxcap$)
2:      route_convexes is an array storing convex_hull for each route
3:      improvements ← True
4:      **while** improvements **do**
5:          **for all** i, j such that i, j are routes index combination **do**
6:              central_point_i ← average of point in convex i
7:              central_point_j ← average of point in convex j
8:              closest_from_i_j ← closest_point(mid_point_i, convex_routes[j])
9:              closest_from_j_i ← closest_point(mid_point_j, convex_routes[i])
10:             **if** closest_from_i_j and closest_from_j_i is Found **then**
11:                 **if** $closest\_from\_i\_j$ fits in route j **then**
12:                     add move to route improvements j
13:                     make the swap
14:                 **else if** $closest\_from\_j\_i$ fits in route i **then**
15:                     add move to route improvements i
16:                     make the swap
17:                 **else if** capacity is not reached by swapping customers **then**
18:                     swap the route-points between i and j
19:                 **if** improvements **then**
20:                     recalculate convex hull of route i and j
21:         **if not** improvements **then**
22:             routes = $elim\_empty\_routes$(routes) **return** routes

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B

LocalSearch Algorithm - Swap if any improvement

Algorithm 4 swap_if_improvement

Require: $dist(A, B)$ returns distance from point A to B

1: **function** SWAP_IF_IMPROVEMENT($route\_i, route\_j, j\_to\_i, i\_to\_j$)

2:     $\texttt{A}, \texttt{B}, \texttt{C} \leftarrow \texttt{route\_i[i\_to\_j-1]}, \texttt{route\_i[i\_to\_j]},$
            $\texttt{route\_i[i\_to\_j+1 mod(\%) len(route\_i)]}$

3:     $\texttt{D}, \texttt{E}, \texttt{F} \leftarrow \texttt{route\_j[j\_to\_i-1]}, \texttt{route\_j[j\_to\_i]},$
            $\texttt{route\_j[j\_to\_i+1 mod(\%) len(route\_j)]}$

4:     $\texttt{old\_distance\_i} \leftarrow dist(\texttt{A}, \texttt{B}) + dist(\texttt{B}, \texttt{C})$

5:     $\texttt{old\_distance\_j} \leftarrow dist(\texttt{D}, \texttt{E}) + dist(\texttt{E}, \texttt{F})$

6:     $\texttt{new\_distance\_i} \leftarrow dist(\texttt{A}, \texttt{E}) + dist(\texttt{E}, \texttt{C})$

7:     $\texttt{new\_distance\_j} \leftarrow dist(\texttt{D}, \texttt{B}) + dist(\texttt{B}, \texttt{F})$

8:     **if** $\texttt{old\_distance\_i} + \texttt{old\_distance\_j} >$
            $\texttt{new\_distance\_i} + \texttt{new\_distance\_j}$ **then**
            swap point B of route i with point E of route j
            return True

C
LocalSearch Algorithm - Move if any improvement

Algorithm 5 move_if_improvement

**Require:** $dist(A, B)$ returns distance from point A to B

1: **function** MOVE_IF_IMPROVEMENT($route\_i, route\_j, i\_to\_j, j\_to\_i$)

2:      A, B, C ← route_i[i_to_j -1], route_i[i_to_j],
         route_i[i_to_j+1 % len(route_i)]

3:      D, E, F ← route_j[j_to_i -1], route_j[j_to_i],
         route_j[j_to_i+1 % len(route_j)]

4:      old_distance_i ← $dist(\texttt{A}, \texttt{B}) + dist(\texttt{B}, \texttt{C})$

5:      old_distance_j ← $dist(\texttt{D}, \texttt{E}) + dist(\texttt{E}, \texttt{F})$

6:      new_dist_before_B ← $dist(\texttt{A}, \texttt{E}) + dist(\texttt{E}, \texttt{B}) + dist(\texttt{B}, \texttt{C})$

7:      new_dist_after_B ← $dist(\texttt{A}, \texttt{B}) + dist(\texttt{B}, \texttt{E}) + dist(\texttt{E}, \texttt{C})$

8:      new_distance_j ← $dist(\texttt{D}, \texttt{F})$

9:      **if** new_dist_before_B $< new\_dist\_after\_B$ **then**

10:          **if** old_distance_i + old_distance_j $>$
         new_dist_before_B + new_distance_j **then**
         move point E from route j to route i before B

11:      **else**

12:          **if** old_distance_i + old_distance_j $>$
         new_dist_after_B + new_distance_j **then**
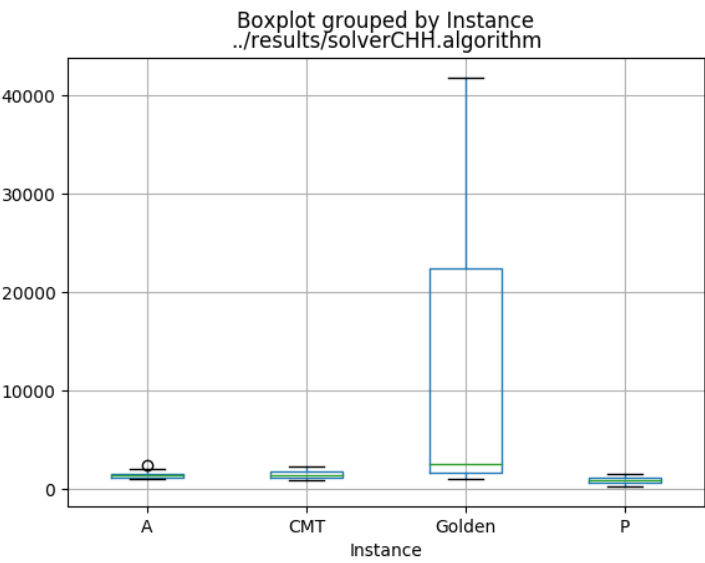   move point E from route j to route i after B
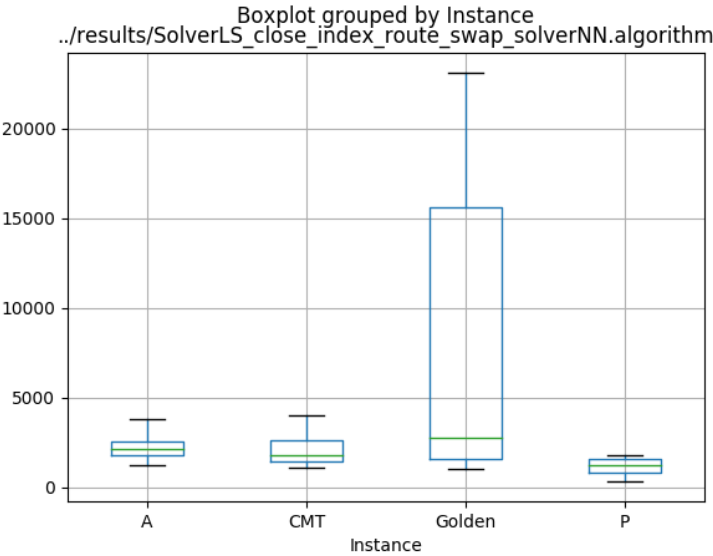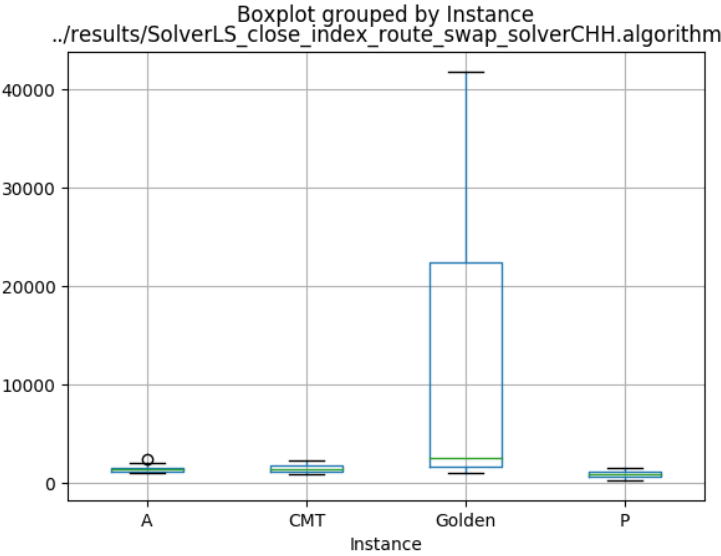

D
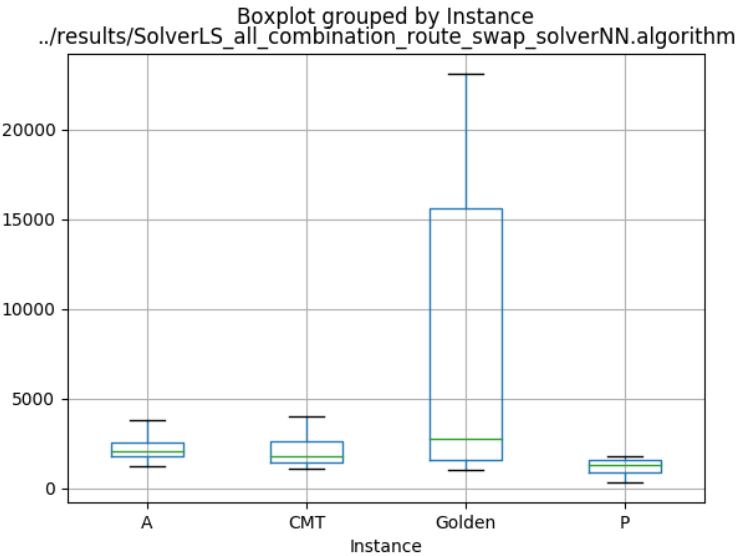# BOXPLOT FIGURES
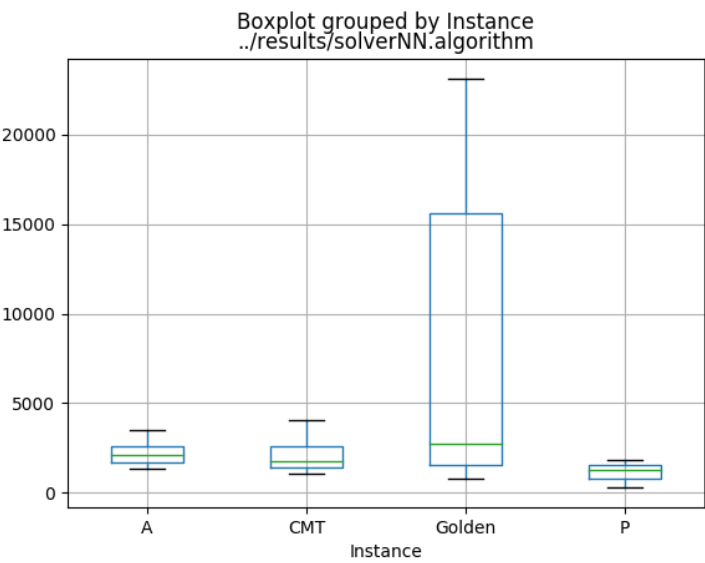
(a) Heuristic NN Algorithm - Custom
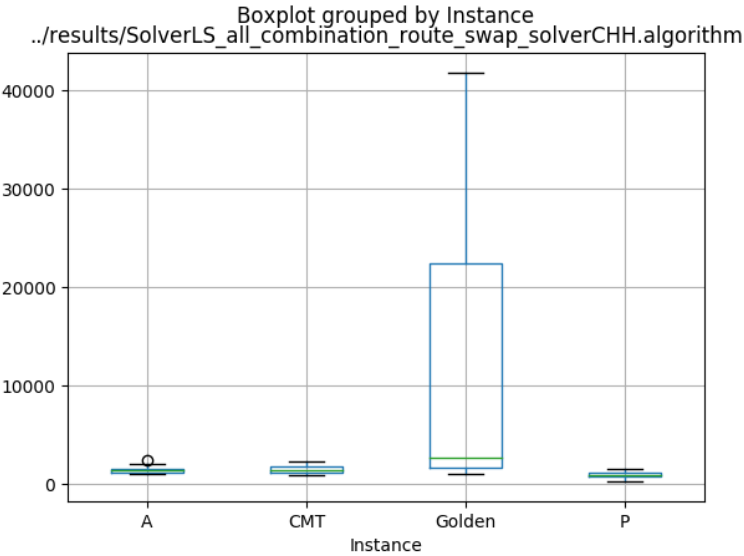

(a) Heuristic Cluster Algorithm - Custom

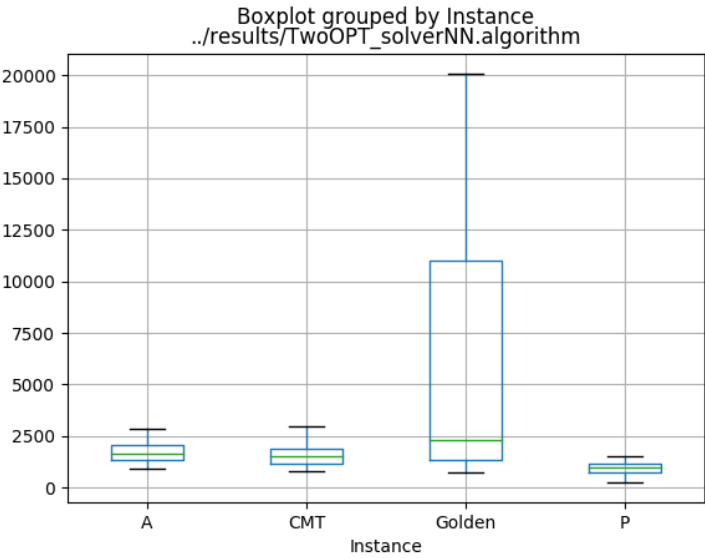(a) Local Search Algorithm - Custom - Close index route for NN heustic

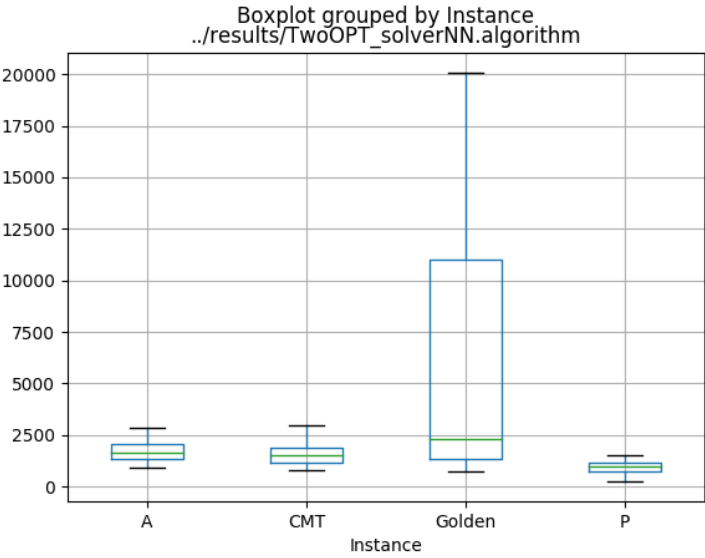(a) Close Index Custom Local Search Figure for cluster heuristic

(a) Local Search Algorithm - Custom - All index combinations route
for NN heuristic

(a) Local Search Algorithm - Custom - All index combinations route
for cluster heuristic

(a) Local Search Algorithm - Known - Two Opt for NN heuristic

(a) Two Opt Known Local Search Figure for cluster heuristic